ACCIDENTS WAITING TO HAPPEN
TAIL ROTOR FAILURES

The tail rotor serves three functions. It balances the torque of the main rotor, it provides directional stability, and it is used for control. Tail-rotor failures can occur in several ways and depending on the type of failure can impact any or all of these functions.

The most serious failure is the entire disappearance of the device because of enemy action or due to a major structural failure. The next most serious is the stoppage of rotation after the severance of the tail rotor drive shaft. And finally, the most survivable failure is the loss of tail rotor pitch control following a severance or a jam in the control system.

Losing the whole thing

The ability to survive the entire loss of the tail rotor depends upon the design of the helicopter and the flight condition at the time of the loss. Helicopters with large vertical stabilizers flying at high speeds cope best. After the failure, the main rotor torque will swing the helicopter around into a sideslip until the opposing yawing moment produced by the side force on the vertical stabilizer is equal to the torque. If the engine power required to fly in the sideslip is not too large, it may be possible to continue level flight. Even without the tail rotor, turns can be made using the cyclic stick.

The original specifications for the Utility Tactical Transport Aircraft System, which became the Sikorsky Black Hawk, and the Advanced Attack Helicopter, which became the Hughes (now Boeing) Apache, stipulated that after losing the tail rotor they should be able to maintain level flight with no more than 20^{o} of sideslip at the speed for minimum power.

To meet this requirement, all the respondents designed large vertical stabilizers, which, without the help of the tail rotor, could overcome the natural instability of the fuselage and provide the yawing moment required to balance the torque of the main rotor at the specified conditions.

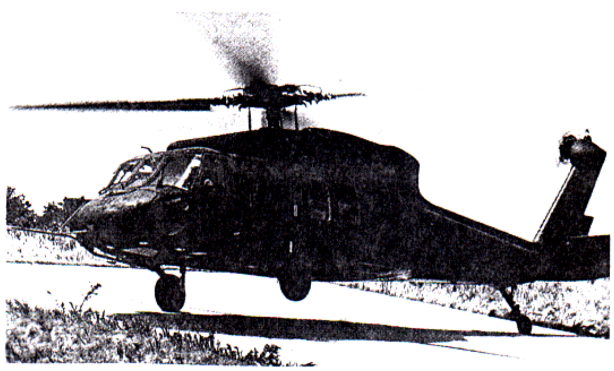
This was true at Hughes, but after the award of the Apache contract and as the configuration matured, the capability to satisfy the requirement deteriorated. Significant changes demanded by the Army included an increase in design gross weight and the substitution of Hellfire anti-tank missiles for the smaller TOWS, with an increase in drag. Another adverse change was the destabilizing effect of replacing the nicely curved canopy panels with flat panels in the interest of reducing omnidirectional sun glare.

To compensate for these changes, the area of the vertical stabilizer was increased by 20%. Despite this change, wind tunnel tests of a 1/7 scale model and calculation of power required in a sideslip indicated that the requirement could not be satisfied at 80 knots--the speed for minimum power. It could, however, be met at any speed above 125 knots where the sideslip angle would be less than the 14^{o} stalling angle of the fin.

Unfortunately, even this more-or-less satisfactory conclusion had to be abandoned when early flight tests showed that the Apache could not meet its sideward flight goal of 40 knots. The reason was traced to the drag and blockage of the large fin. When part of the lower trailing edge was removed, the sideward flight goal was met, but the ability to fly home in level flight without the tail rotor was lost.

The Army decided that the sideward flight performance was more important and reluctantly changed the loss-of-tail-rotor specification to allow a partial-power descent in forward flight, but at no more than 1,000 feet per minute.

You can still see the result of this compromise by looking at the Apache's fin. The same explanation apparently accounts for the odd look of this surface on both the Sikorsky Black Hawk and the Kaman Seasprite.



A pilot faced with the complete loss of a tail rotor in forward flight can, theoretically and with a lot of luck, survive by going into a partial-powered descent with lots of sideslip and at the last moment cutting power to make a run-on landing. If the loss occurs in hover, the recommended action is the same as with an engine failure--immediately go into autorotation

The stopped tail rotor

When a tail rotor stops rotating because of a broken tail-rotor drive shaft, the situation is only slightly less traumatic than the loss of the entire tail rotor. The stopped blades will act partially as additional fin area and will increase the antitorque effect of sideslip, but the effect is essentially the same as losing the whole tail rotor.

A possible source of tail-rotor shaft failure is the very high torque that is required to drive the tail rotor if it is stalled. A scenario for this possibility involves stopping a fast right hover turn (for helicopters whose main rotor turns counter-clockwise when seen from the top). In the turn, main rotor torque is producing the turn rate and the tail rotor blades are operating at low pitch angles.

When the pilot stomps on the left pedal to stop the turn, the pitch is suddenly increased by 20^{o} to 30^{o}. The induced velocity through the tail rotor cannot change instantaneously, and so for a while, the blades operate at angles of attack approximately equal to the pitch change--usually above their stall limits.

Thus, the tail-rotor drive system can be subjected to a torque spike that is several times higher than what would be experienced in other maneuvers.

Sikorsky s fix

This was a problem for the first version of the Sikorsky S-58, the anti-submarine HSS-1. To make it compact for storage aboard a ship, the designers had provided for folding the tail boom just forward of the fin. The disconnect in the tail rotor drive shaft consisted of two "face gears" which engaged each other in normal operation. Early flight tests disclosed that these gears failed under the high transient torque when suddenly stopping a right hover turn.

Sikorsky's fix was to install dampers at the rudder pedals so that the pilot could not move them quickly. These dampers became a part of all subsequent Sikorsky designs. Other companies have relied on training or warnings in the Pilot's Operating Handbook to avoid sudden pedal movements.

Another possible source of tail-rotor shaft failure is enemy action. The Army's vulnerability requirement for the Hughes/McDonnell Douglas/Boeing Apache was that no single .50-caliber round could do enough damage that the mission had to be aborted. In the case of the tail-rotor shaft, making it from a large diameter tube satisfied this requirement. The decision was verified by shooting a hole in the shaft and then proving that it could still take the required torque in the structures test laboratory.

Severance of the control system

Another possible type of failure is one that leaves the rotor turning. Severance of the control will result in the blades going to flat pitch. This is due to the "tennis racket effect" in which centrifugal forces acting on mass elements in front and behind the feathering axis will force the blade to go to the position where the twisting moment due to these forces is zero.

Even though no control is available, the spinning tail rotor at flat pitch still adds significantly to the directional stability and to the antitorque force generated by sideslipping. Thus, there is a possibility of maintaining level flight. Of course, no hover is possible so a run-on landing from autorotation is called for.

The Apache has a feature known as the Back-Up-Control-System (BUCS). It detects a severance if the pilot moves a control and nothing happens at the actuator. That control channel immediately becomes "fly-by-wire" using the electronic stability and control augmentation system which automatically changes from its normal limited-authority mode to full authority. Since this is a back-up system, the pilot is advised to finish quickly what he is doing and head home for repairs.

Control jam

Another control system failure is a jam due to a misplaced tool or to battle damage. This is the only tail rotor failure that can be easily practiced in flight. The instructor locks up the pedals with his feet and says "Pedals jammed. What do you do now?"

If the "jam" is initiated at a speed above that for minimum power, the student should remember that there is some lower speed where the same tail rotor pitch is the right value for level flight with zero sideslip. By adjusting speed and power while letting sideslip become whatever it wants, he should be able to maneuver himself to that speed and perhaps even to a slower one for a run-on landing. Lots of Luck!!

The BUCS on the Apache was also designed to live with a control jam. Each of the control channels has a shear pin. When the pilot breaks it against a jam, the system treats it as a severance and goes to its fly-by-wire mode.

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